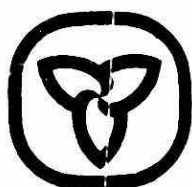


GAMMA IRRADIATION TREATMENT OF SECONDARY SEWAGE EFFLUENT

A Report on a Pilot Plant Study

RESEARCH REPORT W 59

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Ontario

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Minister

Everett Biggs,
Deputy Minister

Gamma Irradiation Treatment of
Secondary Sewage Effluent

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A.H. Vajdic

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ABSTRACT

The operation and monitoring of a pilot scale Co-60 gamma irradiation unit treating secondary sewage effluent is described.

The disinfecting efficiency of the unit is compared to that of an experimental 'ideal' chlorination unit and to the plant chlorination process.

A cost estimate for disinfection by gamma irradiation on a full plant scale is included.

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Gamma Irradiation Treatment of
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INTRODUCTION

For the protection of receiving waters, many agencies are advocating the continual disinfection of sewage effluents. Chlorine, which is the most widely used disinfecting agent, is an oxidant; as well as inactivating microorganisms it will combine non-specifically with the organic matter present in secondary effluents, the amount available for disinfection thereby being depleted. Additionally, microorganisms embedded in suspended solids are protected from the chemical, since chlorine can only penetrate such solids slowly.

Further, upon disinfection with chlorine, chloramines are rapidly formed in the effluents; these chloramines are toxic at very low levels to many forms of aquatic life (1,2) and can persist for long periods. The procedures necessary to enhance the efficiency of the chlorination process are often inadequately applied (3); these would include modification of the method of chlorine application, optimization of chlorine contact chamber design to yield the nominal retention time and improvements in process control. The need for such modifications in chlorination practice, in order to meet disinfection requirements with the lowest possible chlorine residuals, has not yet been fully acknowledged (4).

A reassessment of sewage disinfection, both by chlorine and alternative processes, from the point of view of maximizing efficiency and reliability and minimizing the generation of substances toxic to aquatic and human life, is therefore currently in progress. These studies have also received impetus as a result of the energy crisis, which it is predicted will result in a shortage of chlorine (5).

Gamma irradiation has long been used in the sterilization of drugs and foodstuffs (6,7) and more recently, hospital supplies. The disinfecting effect of gamma irradiation remains relatively unchanged in the presence of organic matter, and the irradiation has the capability of penetration into particulate matter.

Laboratory studies by the MOE on the use of gamma irradiation for the disinfection of municipal waste effluents were carried out in 1971 (8). There have been several other studies (9, 10, 11) on the application of irradiation in the treatment of secondary effluents. None of these were carried out on a pilot scale under practical running conditions; one other investigation (12) describes an irradiation installation as a terminal process to a conventional aeration package plant.

This report details the operation of a pilot scale irradiation unit, constructed by Geodel Inc.* at the site of a 10 million gallons per day (MGD) water pollution control plant (WPCP) located at Burlington, Ontario. The 18 month study was completed in May of 1973.

* Geodel Inc., Georgetown, Ontario.

DESCRIPTION OF STUDY

Plant Layout

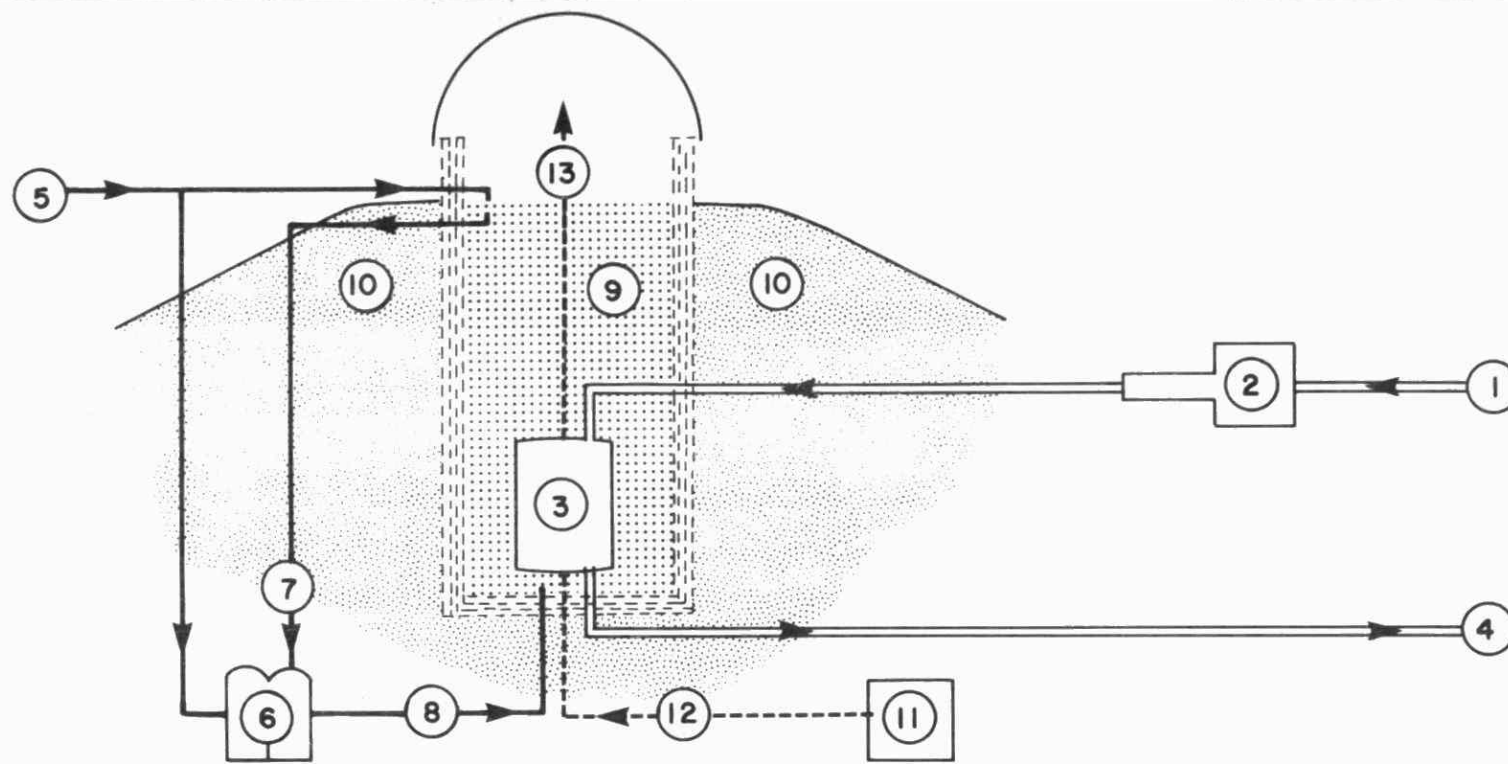
Burlington Skyway WPCP, is a conventional extended aeration plant, treating sewage from a predominantly residential area. The area does not have separate storm sewers, and fluctuations in flow and sewage strength can be particularly pronounced during rainfall, with plant wash-outs occurring if storm water volume becomes excessive.

The irradiator process flow diagram is shown in Fig. 1. Clarified secondary effluent was pumped from the overflow channel of the clarifier to the irradiator; the rate of flow could be varied, within the limits calculated to ensure turbulent flow, to provide the necessary residence time within the unit for the required dosage. Thus the dosage of 50,000 rads⁺ was obtained at 10 gpm (gallons per minute) flow and the dosage of 100,000 rads was obtained at 5 gpm flow. A dosage of 300,000 rads was used for a short period only, during experimentation to determine the extent of chemical change resulting from irradiation. Irradiated effluent was wasted into the outfall of the WPCP.

The irradiator (patent pending) was fabricated of passified stainless steel and consisted of a closed unit incorporating a series of annuli containing over and under baffles with a total volume of 70 cu. ft.

Pencils of Co-60 totalling 39,900 curies, were located in holders within the unit around an inner annulus. The design of

+ a rad is an energy unit defined as the absorption of 100 ergs/gm of material



- LEGEND :
- | | |
|---------------------------|-----------------------|
| 1. Secondary effluent in | 7. Pool water return |
| 2. Pump | 8. Pool water supply |
| 3. Irradiator | 9. Pool water shield |
| 4. Secondary effluent out | 10. Earth shield |
| 5. Municipal water in | 11. Sparge gas source |
| 6. Deionizer | 12. Sparge gas in |
| | 13. Sparge gas out |

FIG. 1. Burlington Skyway WPCP, Gamma Irradiator – Process Flow Diagram

the unit provided for the most efficient use of the emitted irradiation; the dose rate remained relatively constant throughout the study. The irradiator unit was located at the base of a 20-foot deep, 10-foot diameter protective pool, into which only minimal irradiation escaped. Water from the pool was continually circulated through a deionising column, and was monitored for evidence of radiation leakage from the irradiator. A series of fail-safe alarms, as specified by Atomic Energy of Canada Limited (AECL) were incorporated, and the installation was covered by a lockable metal silo roof.

Dye tracer studies ** to determine the mixing characteristics and residence time of the irradiation vessel were performed using Rhodamine WT. Figure 2 shows the variation in retention times within the reactor vessel for a 'plug' of tracer dye added to the influent. At the flows tested, the experimental mean retention time corresponded with the theoretical retention time. A comparison of the two sets of experimental data to two theoretical distributions, indicates that the degree of mixing present lies between that for 2 tanks in series and 3 tanks in series.

As the composition of clarifier effluent was expected to vary, preliminary studies ** were conducted to determine the extent and reproducibility of inactivation of microorganisms by irradiation. Using the Gammacell 220 (AECL) employed in previous studies (8), batches of four different grab samples of secondary

** Courtesy K.L. Murphy, ref. #(19)

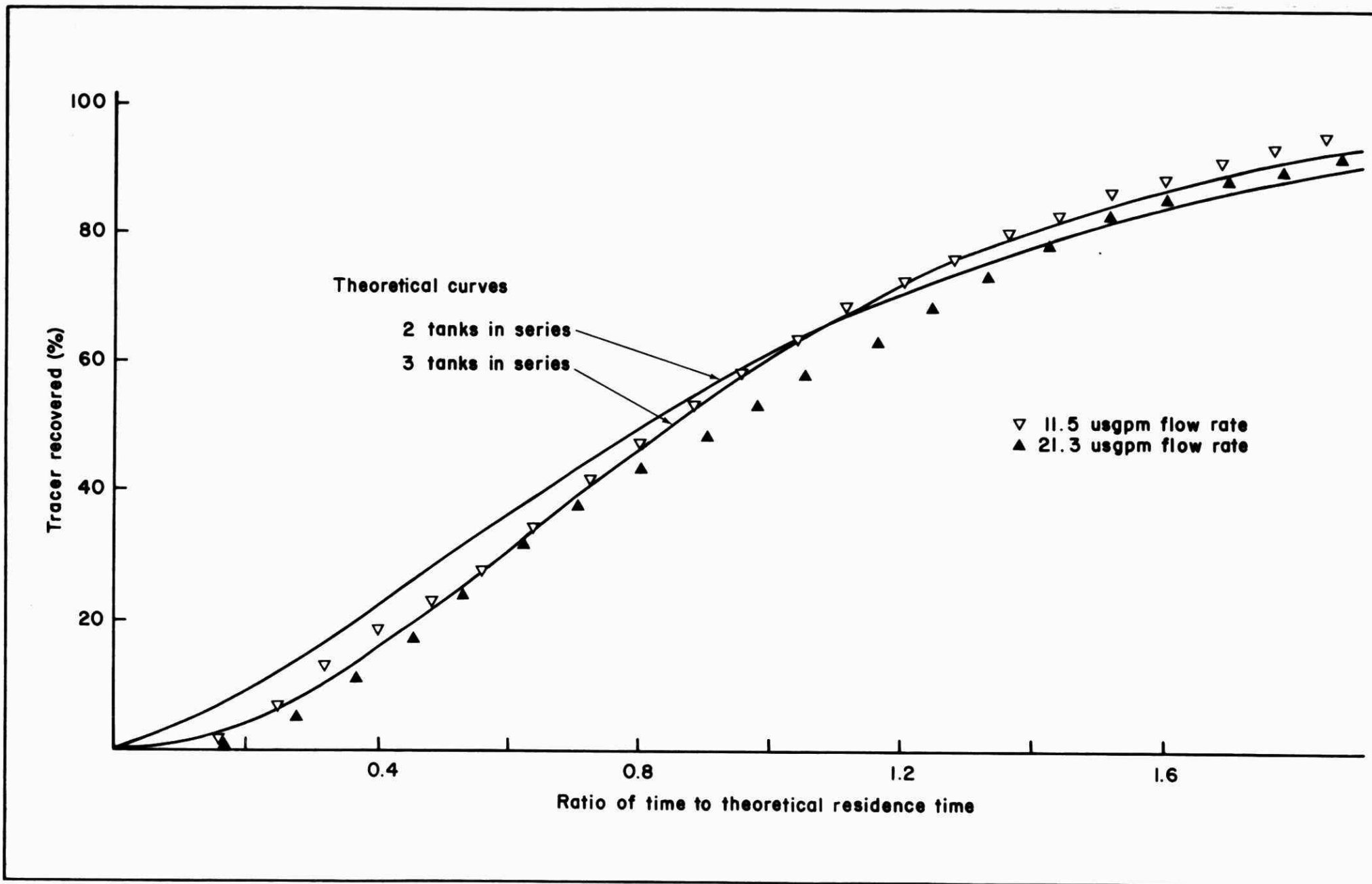


FIG. 2. Variation in Irradiator Residence Time

effluent were subjected to dosages of 1.1×10^4 to 1.5×10^5 rads, applied at about 1.6×10^4 rads per minute; input of total coliforms in the samples varied from a low of 3.5×10^4 per 100 ml to a high of 1.5×10^6 per 100 ml, enumerated by the standard membrane filter technique. The results, shown in Figure 3 indicated that, for a range of zero to 99.9% inactivation of total coliform organisms, a semi-logarithmic relationship existed between the surviving ratio and irradiation dosage which could be expressed:-

$$\frac{c}{c_0} = 10^{-0.57 R}$$

where c - no. of coliforms after irradiation
 c_0 - initial no. of coliforms
 R - rads $\times 10^{-4}$

Beyond a dose of 100,000 rads, a 100% kill of coliforms was obtained.

No significant variation in inactivation was evident for the four different samples.

Since the treatment plant effluent would only be chlorinated from May to September, and not for the full duration of the study period, a small experimental chlorine contact tank was fabricated, consisting of four compartments divided by over and under baffles. The design gave a nominal detention time of 30 minutes, and chlorine was applied as a hypochlorite solution. The residual chlorine, as measured by the orthotolidene method was 0.5 mg/l in the effluent from the contact tank. Since this system should have good plug-flow characteristics and good initial mixing of disinfecting solution and clarified effluent,

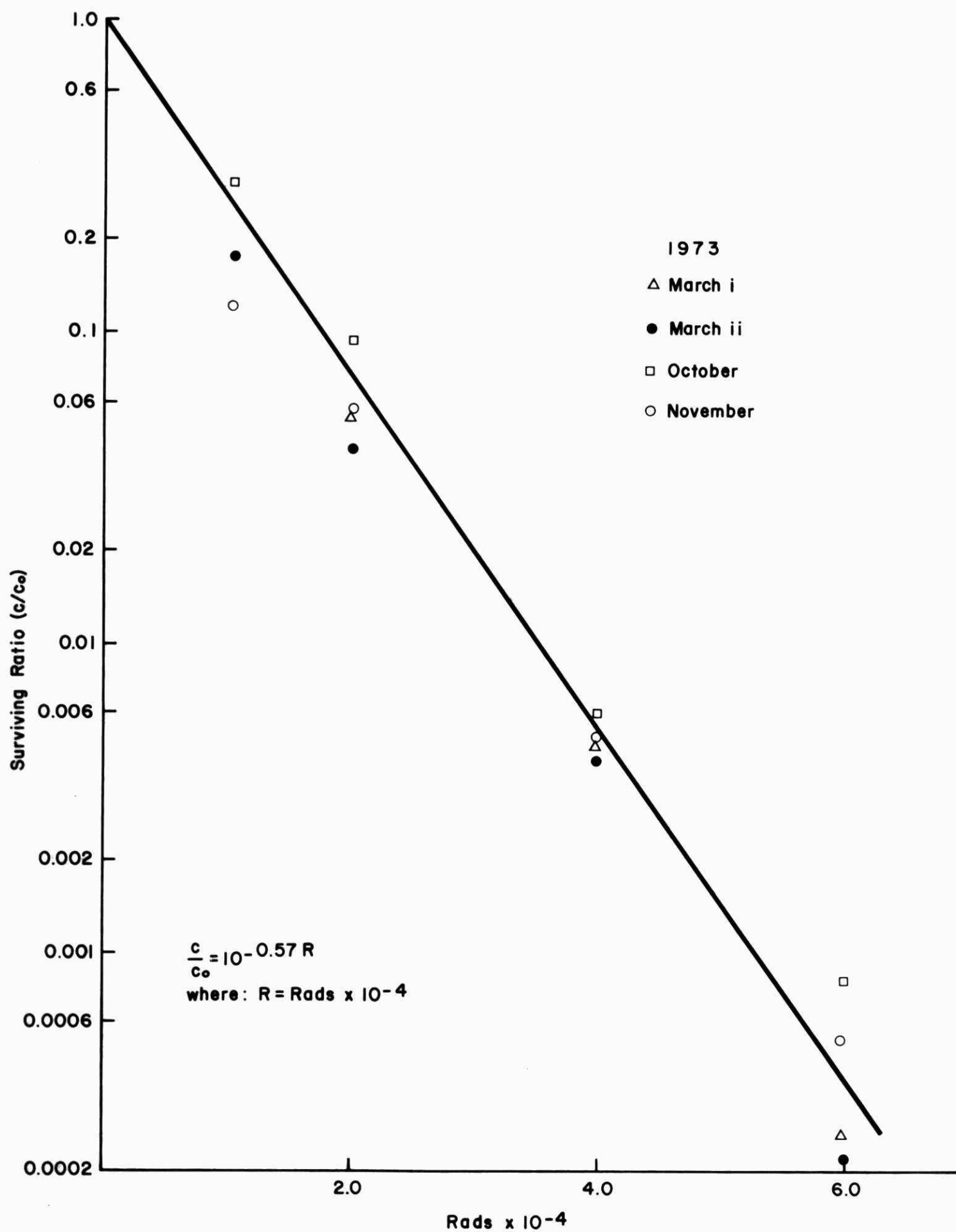


FIG. 3. Coliforms Surviving Irradiation - Gammacell 220

the chlorinated effluent represented that from a more or less 'ideal' chlorination system.(13)

The actual plant effluent is chlorinated, and after passing through only a short mixing channel, discharges into an outfall sewer which acts as an additional contact chamber; plant chlorinated samples could be taken only at the end of the mixing channel after a nominal 15 minutes of contact with chlorine, and thus did not have the benefit of the additional contact time of the outfall.

Monitoring Procedures

Monitoring of the operation of the Burlington irradiator was designed to reveal the full potential of gamma irradiation for both disinfection and the alteration of those parameters normally employed to indicate the quality of sewage effluent. Conditions affecting the performance of the reaction vessel were evaluated, thus providing actual design data.

Samples of clarifier effluent (C), irradiated clarifier effluent (CI) and clarifier effluent following experimental chlorination (CL) were collected; as well as grab samples, it was possible to collect 24-hour composites by means of solenoid valves set into the lines. Grab samples only, of plant chlorinated effluent (CLP) were taken when the plant chlorinator was in operation. Special flow-through holders were installed in the C and CI lines, for virus isolation studies using Moore swabs.

Test Procedures

1. Bacteriological

All bacteriological testing was carried out on grab samples, taken in standard (6-oz) sterile bottles, shipped

to the laboratory on the same day. Bottles containing sodium thiosulphate were used, where a chlorine residual existed in the sample.

The following tests were carried out:-

1. Coliforms, fecal coliforms and fecal streptococci were enumerated using the standard membrane filter technique.
2. Total counts were made using the pour plate technique, wherein samples were diluted to the appropriate level in buffered water and plated in tryptone-glucose-extract agar (Difco). The plates were incubated at 35°C for 48 hours, and counts were made with the aid of a Quebec colony counter.
3. The presence of *Salmonellae* was determined following the slightly modified method of Yoshpe-Purer et al (14). Portions of 200 ml of the various samples were inoculated into 100 ml of triple strength selenite broth, rapidly warmed to 41.5°C and then incubated at this temperature for 24 hours. The selenite cultures were then plated on to both brilliant green and bismuth sulphite agar (Difco), and incubated at 37°C for 24 hours. Each suspect colony from the plates was transferred to urea as well as triple-sugar-iron agar (Difco); those showing typical reactions were confirmed serologically using Spicer-Edwards antiserum (15).

Recoveries of *Salmonellae* using the above method with grab samples were initially unsuccessful, and it was therefore decided to culture the Moore swab from the C and CI lines. After the swabs had been processed for virus isolation, the whole swabs were immersed in single strength selenite broth in large beakers, covered with aluminum foil; subsequent procedures were the same as for the grab samples.

2. Virological

Monitoring of effluents was carried out for two types of virus, human enteric and bacterial viruses. Bacteriophages ('phages) or bacterial viruses have often been used as models for the behaviour of other types of viruses. For this study, it was felt that useful information could be obtained by monitoring for bulk 'phages with *E. coli* B, as well as attempting to isolate human enteric viruses.

1. Bulk bacteriophages were enumerated in grab samples by the most probable number (MPN) method, developed by Kott (16) and modified by Vajdic (17). In addition, 50 ml of effluent sample was added to 50 ml of double strength lauryl tryptose broth, followed by the addition of host bacterium *E. coli* B; after the incubation and plating out procedure of the MPN method, the presence or absence of 'phage in the 50 ml sample could be determined.
2. Human enteric virus sampling was carried out using the Moore swab technique with Kotex sanitary napkins, folded and secured within a double layer

of gauze, being placed in the special flow-through fittings in C & CI lines for a 24 hour period. The swabs were put into plastic bags and viruses were extracted by adjusting the bag fluid pH to between 8.0 and 9.0 with normal NaOH, followed by the addition of 10-20 ml of 3% beef extract. After vigorous kneading the extracts were collected and treated with an equal volume of chloroform at 4° C overnight. The aqueous layer was inoculated on to primary monkey kidney cells using standard procedures.

3. Chemical

Following standard procedures, 24-hour composite samples of C, CI and CL were collected; grab samples of the plant-chlorinated effluent were taken.

Determinations of suspended solids, TOC, BOD, COD, total phosphate, ammonia, nitrate, nitrite, total Kjeldahl nitrogen, colour, turbidity and detergents were carried out using standard procedures.

4. Toxicity

As a gross measure of effluent toxicity, two aquaria were set up, one receiving CL and the other CI; the flow rates were adjusted to provide approximately a complete volume change in each aquarium 4 times per day. Each aquarium was then stocked with 15 young goldfish (2 cm - 8cm in length, Hartz Mountain, Toronto). Previous tests had indicated that, when aeration from a standard aquarium aerator was provided, such fish could

survive in C for at least as long as 6 weeks, with no apparent ill effects.

EXPERIMENTAL RESULTS AND DISCUSSION

Enteric viruses were not isolated in the swabs from either the C or CI lines.

In the experimental chlorine contact chamber, the average percentage destruction of coliforms, fecal coliforms and fecal streptococci was 98.2, 99.8 and 98.8 respectively, whilst the total count was reduced 98.3% (Table 1). These inactivation levels showed no wide fluctuations from sample to sample, as conditions in the contact chamber were well controlled. Bacteriophages could still be isolated, although in reduced numbers in CL; this indicates that inactivation of enteric viruses, which are thought to be at least as resistant to chlorine as 'phages (18), was probably not complete under these conditions of chlorination. Isolations of Salmonellae were made on several occasions in the C grab samples, but on only one occasion in CL; isolations from Moore swabs place in C were usually positive.

At the 10 gpm flow rate through the irradiator corresponding to a dosage of 50,000 rads, good microbiological kill was obtained. Thus, (Table 1) coliforms were reduced 97.9%, fecal coliforms 83.9% and fecal streptococci 46% on average. These latter organisms have been shown in previous work (9) to be more resistant to gamma irradiation than many other bacteria. Total counts were reduced 93.4% but 'phages could still be isolated in the effluent as could Salmonellae with the aid of a swab. Thus, the inactivation of coliforms approached that level obtained with

TABLE 1 Average* Percentage Inactivation
 of Microorganisms

(after gamma irradiation, compared to
0.5 ppm Cl₂ after 30 minute
contact time)

Organism	Irradiation @ 50,000 rads	Irradiation @ 100,000 rads	Chlorine 0.5 ppm @ 30 min.
Total coliforms	97.9	99.3	98.2
Fecal coliforms	83.9	98.1	99.8
Fecal streptococci	46.0	84.4	98.8
Total bacteria	93.4	97.0	98.3
Bacteriophage	Present	Present	Present
Salmonellae	Present	Present	Present **

* determined from a minimum of 12 random observations

** only 1 positive isolation during the study period.

efficient chlorination, but that for fecal coliforms and fecal streptococci was considerably lower; reduction of total bacteria was also not as efficient.

Irradiation at 5 gpm ie. 100,000 rads dosage, produced inactivations greater than those at the lower irradiation dose, as shown in Table 1. Bacteriophages could still be isolated in the effluent, along with Salmonellae organisms.

Although average percentage inactivations are given for irradiated samples, it is important to emphasize that the individual values did not normally show wide ($> 20\%$) deviations from the average value even though the quality of C did vary, at times substantially; this reinforces the findings of Figure 3.

The microbiological results obtained in the plant chlorinated effluent (CLP), as compared to those in the experimental chlorinator (CL) are shown in Table 2. As can be seen chlorination as practised on a plant scale appears to produce widely fluctuating effects on bacterial numbers; by contrast results from the experimental chlorinator are consistent with respect to bacterial inactivation.

From knowledge of the coliform inactivation rate by irradiation (Figure 3) and the reactor characteristics (Figure 2) it was possible to predict the disinfecting effectiveness of the reactor with respect to coliforms. Organism kill is a function of total irradiation exposure and is not influenced by the dose rate at which the irradiation is applied (10). As shown in Figure 4, the mean values of the experimental results obtained at different irradiation levels in the pilot unit are compared to the standard

TABLE 2 Average Percentage Inactivation of Microorganisms in
Experimentally Chlorinated Effluent * Compared To
Plant Chlorinated Effluent **

	Coliforms	Fecal Coliforms	Fecal Streptococci	Total	Bacter- iophage	Salmonellae
Experimental	98.22+ (97.23-99.97)	99.77 (98.49-99.91)	98.8 (96.43-99.38)	98.31 (95.63-99.18)	Present	Present x
Plant	16.63 (0-98.95)	16.01 (0-92.23)	12.03 (0-40)	40.67 (0-97.65)	Present	Present

* 0.5 ppm Cl₂ residual, via addition of hypochlorite,
at 30 minutes

** 0.5 ppm Cl₂ residual, via gaseous chlorine, 15 minutes
contact time

x only 1 positive isolation during study period

+ numbers in parenthesis show the lowest and the highest
percentage inactivation

deviation of the replicate runs carried out in the Gammacell 220; the results are comparable, even though the dose rate in the latter differs from that in the former. It can be seen that the appropriate irradiation level for the required degree of disinfection may be selected by varying the quantity of Co-60 and the retention time within the radiation field.

These results demonstrate that application of gamma irradiation treatment on a practical scale has an important advantage over current plant chlorination practices, in that a consistent and predictable kill is obtained. It should be emphasized that both the irradiation unit and the experimental chlorinator were designed using constant flow conditions, whereas chlorine was applied to the plant effluent without flow equalisation. This could account, at least in part, for the fluctuating microbial inactivation levels observed in the plant effluent compared to those in the irradiator and experimental chlorinator.

At the dosage rate of the installation, even at the maximum dosage of 300,000 rads, little change in the measured chemical parameters was detected. Organic carbon determinations, carried out on filtered samples, showed no significant decrease in organic content (Figure 5), whilst the COD results (Figure 6) showed slightly higher influent values. This was particularly noticeable at the 300,000 rads dosage and could have been caused by irradiation-induced oxidation within the irradiator, or by the formation of complexes which subsequently did not react in the COD test.

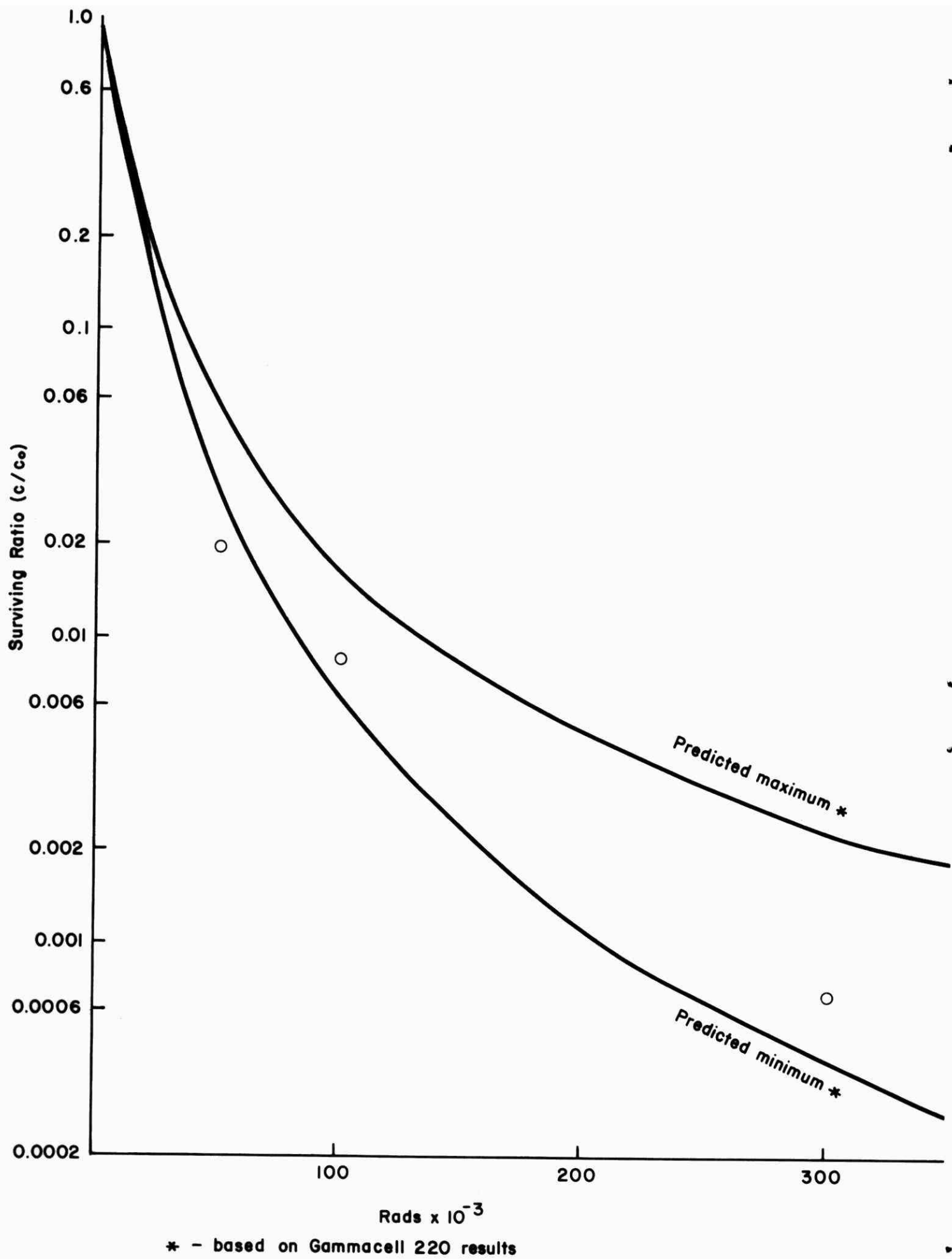


FIG. 4. Coliforms Surviving Irradiation — Burlington Irradiator

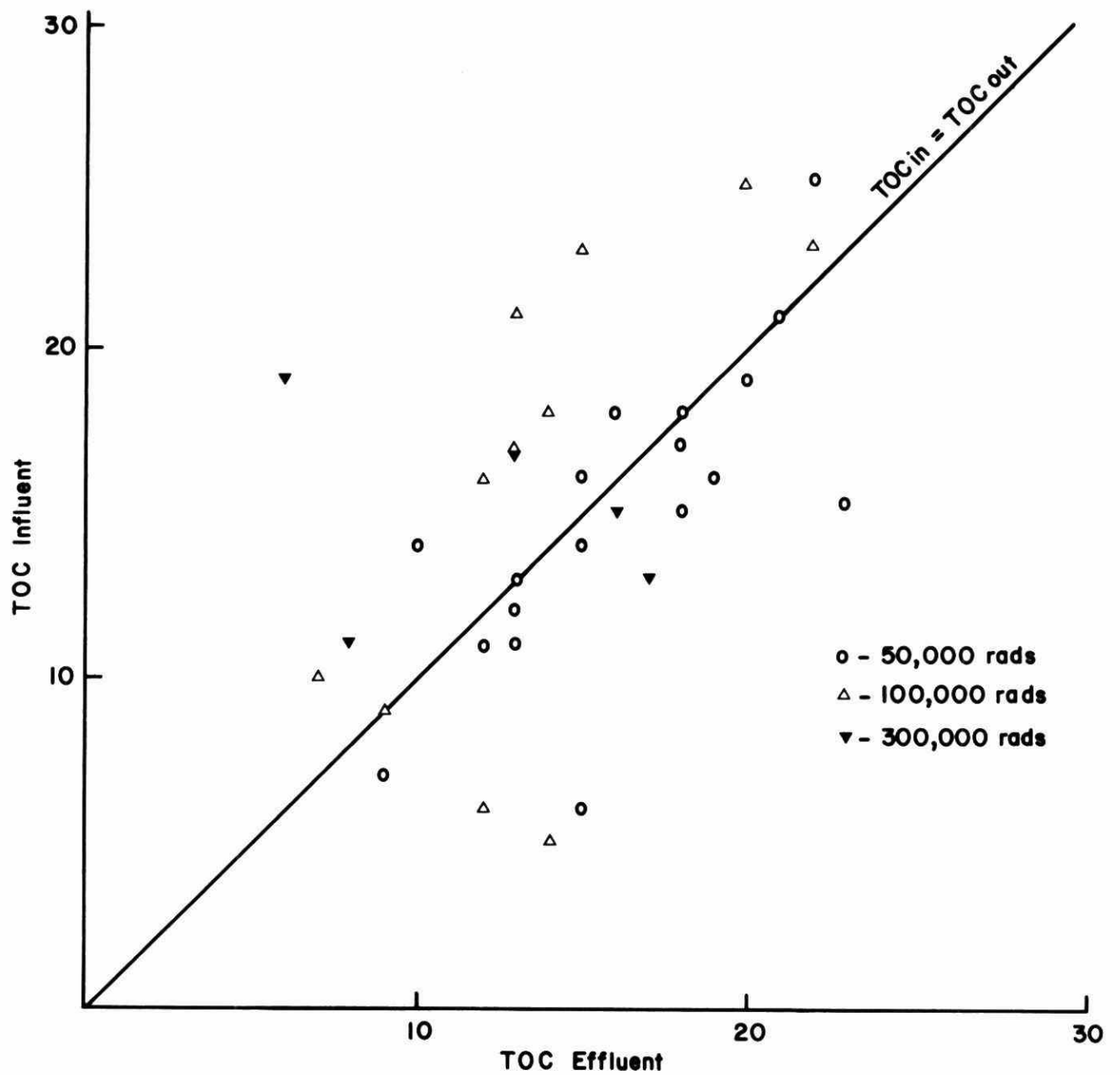


FIG. 5. Total Organic Carbon of Filtered Samples

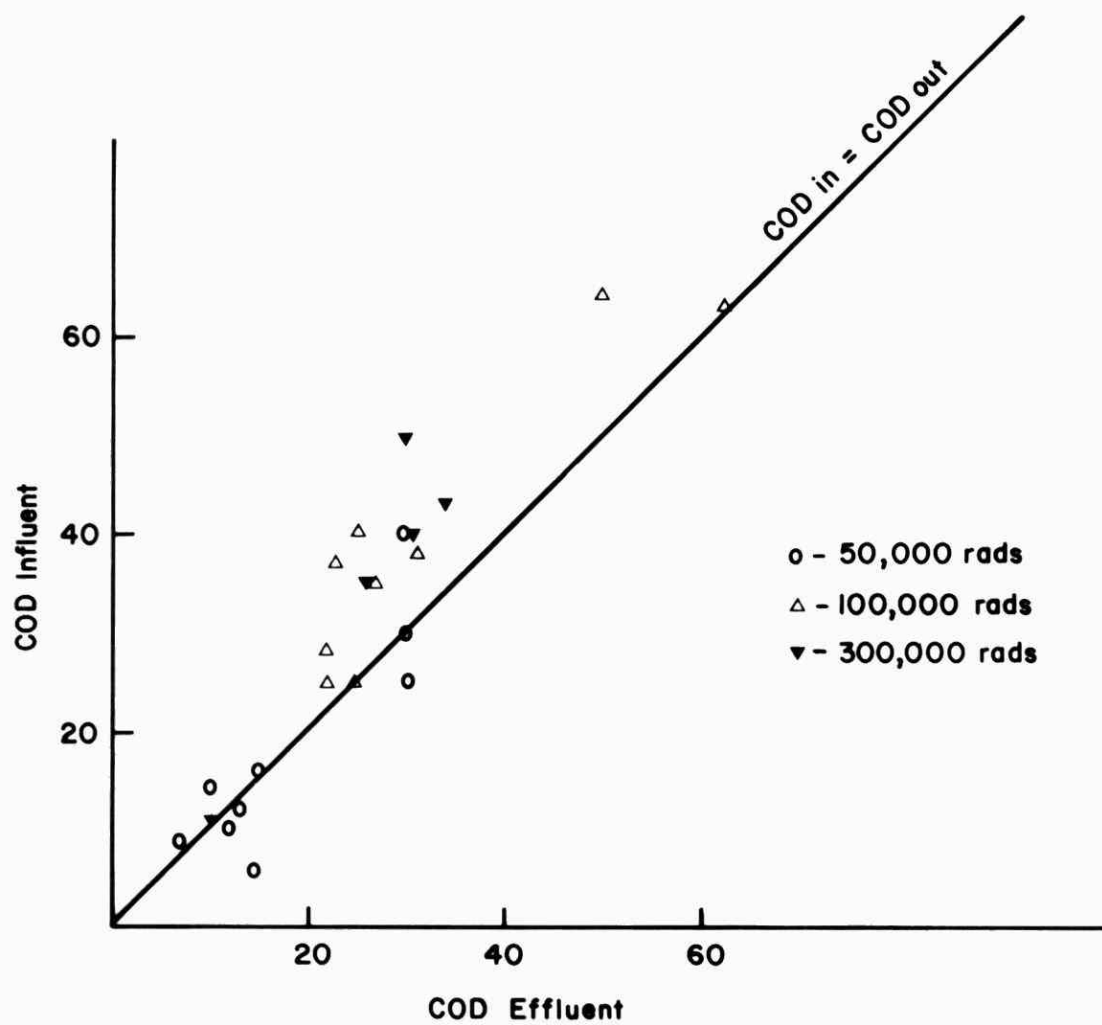


FIG. 6. COD of Filtered Samples

As expected, in the studies of effluent toxicities to fish, the CL passed to the aquarium without holding or dilution, proved rapidly toxic to the goldfish. The goldfish in the irradiated effluent remained apparently unaffected and in good health for periods at least as long as six weeks; after their exposure period to CI, some of these fish were maintained in a standard aquarium for several years.

ESTIMATE OF COST

Values in Figure 7, supplied by Geodel Inc., show the relationship between coliform kill and irradiation dose-cost per thousand gallons, expressed in Canadian dollars and Imperial gallons. The cost quoted is total cost (in 1975 dollars), including capital, capital amortisation and operating expenditures including periodic make-up of the Co-60 load to maintain the dose level. These costs do not include allowances for flow equalisation in the plant to which the irradiation is applied.

For a 99.9% kill, leaving about 100-1000 coliforms per 100 ml in the effluent, the cost would be 64 cents per thousand gallons; for a 90% kill, the cost would be about 18 cents per thousand gallons. A comparable figure for the application of chlorine with normal practices, (4-6 mg chlorine per litre of effluent) at current prices would be 3-4 cents per 1000 gallons.

SUMMARY

A pilot scale gamma irradiation unit was operated at a conventional WPCP; no operating problems were experienced with the unit. Good, consistent bacterial kill was obtained with a dosage of 100,000 rads, equivalent to that obtained in an "ideal" chlorination system. Furthermore, the extent of the kill was predictable,

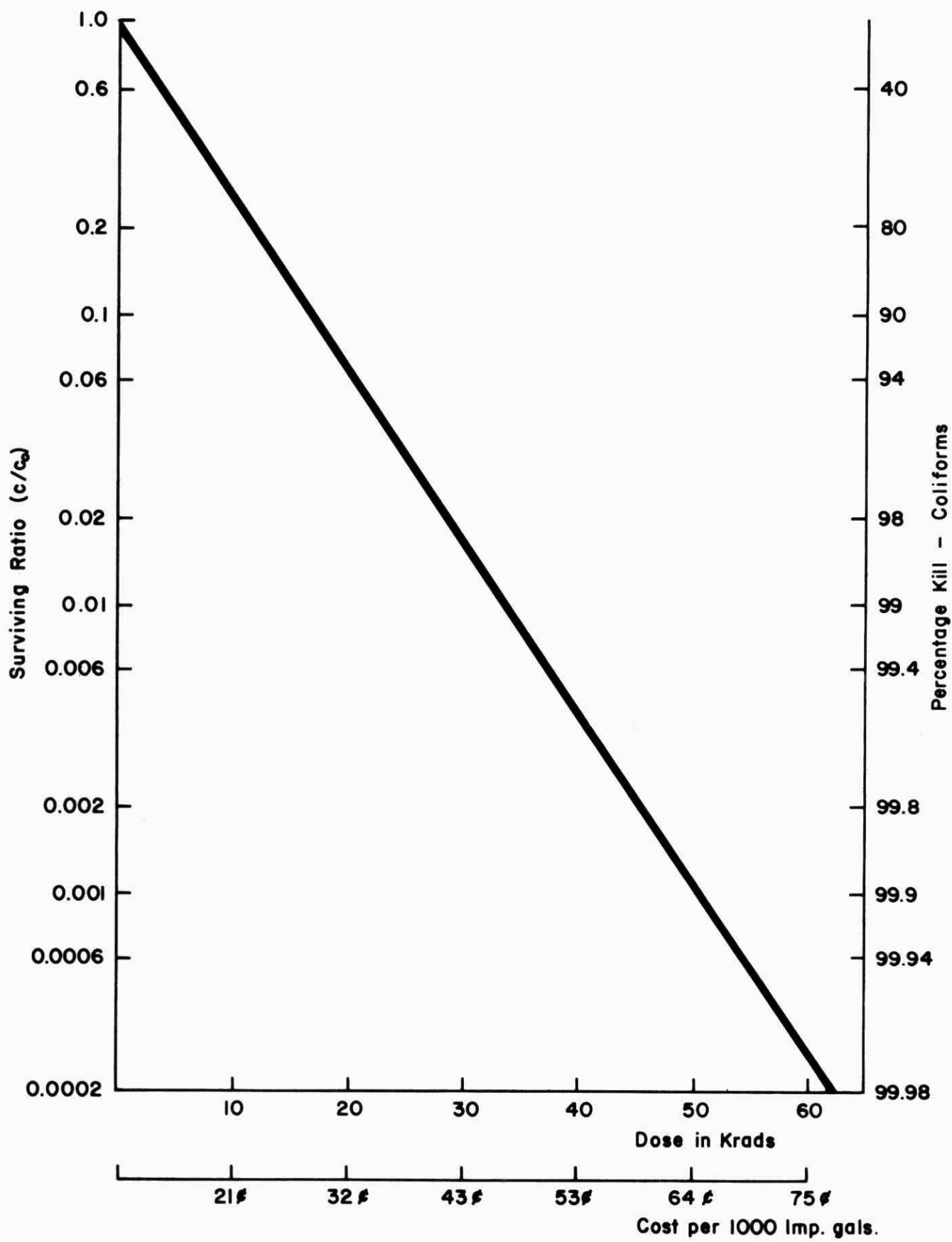


FIG. 7. Cost of Irradiation Treatment vs Percentage Coliform Kill

based on microbial inactivation rates and the reactor design characteristics. The effluent disinfected by gamma irradiation was apparently non-toxic to goldfish, without dilution.

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